LONG-TERM MONITORING OF THE OPR ALTIMETER DATA QUALITY

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1 INTRODUCTION

This yearly report is aimed at presenting the results of the monitoring of the OPR altimeter data quality, from the beginning of the ERS-2 mission (ERS-2 cycle 0) up to the end of cycle 56 (25 September 2000). The goal of this work is to point out possible degradations of instrumental or algorithmic origin which may affect the OPR data quality for a limited period of time, or for the long term. The following parameters are examined :

- the significant wave height
- the backscatter coefficient
- the sea state bias
- the altimeter sea surface height
- the radiometer wet tropospheric correction

The monitoring of these parameters as function of time is performed on one hand by computing simple statistics (e.g., mean and standard deviation over one cycle) from OPR data only, and on the other hand by comparing these parameters with those of TOPEX/Poseidon (TP) mission at ERS/TP crossovers (excepted for sea state bias).

Section 2 is a special section to make the reader aware of the ERS-2 platform attitude control degradation which happened in 2000. This degradation probably impacts the quality of the altimeter parameters, as it will be discussed in the next sections. The next sections give the results for each of the above given parameters.

2 ERS-2 PLATFORM ATTITUDE CONTROL DEGRADATION

Before February 7, 2000, the attitude of the ERS-2 satellite was controlled through a Digital Earth Sensor (measurements on pitch and roll axes), a Digital Sun Sensor (measurements on yaw axis, once per orbit), and three (out of 6 existing ones) gyroscopes (measurements on the X-Y-Z axes) (Vazzana, 2000). Consecutive failures of the gyroscopes leaded ESA to modify the software of the on-board Attitude and Control System (AOCS) to allow it to pilot the ERS-2 satellite with only one gyroscope. The new software has been uploaded on 7 February and the payload was switched on back on February 10. Since this date, altimeter data are produced with only one gyroscope. Gyroscope number 6 has first been used from February 10 to February 16. As gyroscope number 5 was better performing than gyroscope number 6, it has been used since February 16, up to October 7, where it failed (cycle 57). Gyroscope number 6 was used back from October 10 up to October 24. From October 25, gyroscope number 1 is used. It is also important to note that between February 16 and March 3, sun blinding affected the Digital Earth Sensor, leading to significant perturbations of the satellite pointing (Soussi and Zanife (2000), Femenias and Martini (2000)).

3 DATA USED

For ERS-1, the OPR data used cover part of phase C (cycles number 6 to 18 of the first 35-day repeat mission, from October 1992 to December 1993), phase E-F (37-day sub-cycles number 1 to 11 of the geodetic mission, from April 1994 to March 1995), and phase G (cycles number 1 to 13 of the second 35-day repeat mission, from March 1995 to June 1996).

For ERS-2, OPR cycles 0 to 56 (May 1995 to September 2000) have been used.

TP data are the reprocessed Merged Geophysical Data Records in version C distributed by the Archiving, Validation and Interpretation of Satellite data in Oceanography (AVISO) centre. TP cycles 2 to 295 have been used for this study (i.e., data from October 1992 to September 2000). The NASA orbit has been used for the SSH calculation. The main event of the TP mission was the switch off of TOPEX altimeter Side-A and the switch on of altimeter Side-B at TP cycle 236: the mean SSH difference between the two TOPEX altimeters is about 1 cm (AVISO, 1999). This means that at the end of its life, the TOPEX Side-A altimeter measured too high SSH, by about 1 cm. Poseidon cycles have also been used in the long term monitoring of the SSH differences with ERS, but are not used together with TOPEX cycles when computing the TP/ERS mean SSH differences, to avoid extra noise to the (TP-ERS) SSH time series induced by the variation of the relative SSH bias between TOPEX and Poseidon, especially at the end of the life of the Side-A altimeter. The ERS/Poseidon mean SSH difference series is however more noisy than the ERS/TOPEX one because of the smaller number of crossovers used to compute the mean.

The reader is invited to refer to a previous study (Stum et al. 1998), for a detailed presentation of the data processing needed to get an homogeneous TP/E1/E2 dataset. For ERS-1/2, the new SPTR corrections are used and are responsible of the changes with respect to previous yearly reports. Corrections given in the routine validation reports sent to the users with the OPR CDROM's are applied.

4 BACKSCATTER COEFFICIENT LONG TERM MONITORING

4.1 USING OPR DATA ONLY

The impact of the ERS-2 platform attitude control degradation on the OPR altimeter backscatter coefficient has been studied by Dorandeu et al. (2000). They computed the daily mean of OPR altimeter backscatter coefficient and correlated the changes of this daily mean with the attitude control degradation. Their technical note has been made available to the OPR users at the end of August 2000 on the IFREMER Web site. Their main conclusions were the following :

- From January 16 to February 7 : the backscatter coefficient experienced a drop of about 0.15 dB.

  The reason of this drop has not yet been explained. It is not correlated to an on-board anomaly. Although sun blinding occured between January 10 and January 26 (Harrison, 2000), the three gyroscopes were still operating at that time.

- From February 10 to March 2 : the backscatter coefficient experienced a drop of about 0.2 dB

  This drop seems correlated with the implementation of the new AOCS software using gyroscope 6 (February 10 to February 16) and then gyroscope 5 during sun blinding.

- From March 3 onwards : the backscatter coefficient experienced an increase of about 0.1 dB

  This increase seems correlated with the use of gyroscope 5, which performed better than gyroscope 6, and thus reduced the mean mispointing of the platform, leading to higher backscatter coefficient.

Figures 1 to 4 show the histogram of the OPR backscatter coefficient before January 16, between January 17 and February 6, between February 10 and March 2, and after March 4 respectively. The change of the mean value of the backscatter coefficient before and after January 16 does not seem induced by a simple shift of the histogram towards lower values (which would be observed in presence of mispointing) : the enhance of the secondary peaks on the left of the main peak seems the consequence of a modification of the altimeter performance.

For the present long-term monitoring of the backscatter coefficient, no empirical correction of the OPR backscatter coefficient has been made using the values reported above. The mean, median, standard deviation and skewness are computed cycle per cycle. The backscatter coefficient value corresponding to the peak of the histogram, as well as the percentage of samples in the peak bin and in the median bin are also computed, to detect a possible modification of the histogram shape with time. Figure 5 shows the values ot these parameters plotted versus the ERS-2 cycle number. The conclusions reported in Dorandeu et al. (2000) are still valid. A significant change in backscatter coefficient statistics occured during cycle 50 (24-01-2000 to 28-02-2000). This change affected the mean, median values and the peak of the distribution (top figure), as well as the percentages of samples in the peak and median bins (bottom figure). The statistical values from the last cycles (55, 56) are closer to those from before cycle 50, but the mean value of the backscatter coefficient is still about 0.1 dB lower than before cycle 50.

4.2 AT ERS/TP CROSSOVERS

The comparison between TP and ERS-1/2 has been performed by computing backscatter coefficient difference at dual TP-ERS-1/2 crossovers, with a maximum crossover time lag of 1 hour. Estimates of the differences are made over time periods of 12 TP cycles, to get means representative of the same backscatter coefficient samples. The means obtained are running means, (i.e. the first estimate of the mean is made over TP cycles 2 to 13, the second over TP cycles 3 to 14, etc…). It was also interesting to report separately TOPEX and POSEIDON altimeters. In the case of POSEIDON, crossovers with ERS are representative of one 10-day cycle : it must be kept in mind that, as the number and geographic location of 1-hour time lag TP-ERS crossovers vary from one POSEIDON cycle to the next one, they may not sample the same sea state, and this may add noise to the (POSEIDON – ERS) values. Figure 6 shows the (ERS – TP) backscatter coefficient differences versus the series of 12 TP cycles. No anomaly of the ERS-2 backscatter coefficient is observed during the TOPEX Side-A altimeter functioning period : the increase of the ERS-2 – TOPEX series in the last year before the Side-B altimeter switch on is due to the TOPEX Side-A altimeter degradation, which is corroborated by looking at the steady ERS-2 – Poseidon series during the same period. During the TOPEX Side-B altimeter functioning period, the most prominent feature is the ERS-2 backscatter coefficient drop, which is confirmed both by TOPEX Side-B and Poseidon altimeters.

5 SIGNIFICANT WAVE HEIGHT LONG TERM MONITORING

5.1 USING OPR DATA ONLY

Figure 7 shows the same statistics as figure 5, but for the altimeter significant wave height (SWH). No SWH anomaly can be evidenced from figure 7.

5.2 AT ERS/TP CROSSOVERS

Figure 8 shows the results of the (ERS – TP) SWH differences versus the series of 12 TP cycles. For the ERS-1 series, there is a 15 cm jump between the 168-day repeat cycle phase (OPR in version 3) and phase G (OPR in version 6), as expected (see Stum et al., 1998). The main feature of figure 6 is the low drift over time of the TOPEX Side-A SWH which is deduced from the (ERS-2 – TOPEX) series, the return to a normal behaviour with Side-B, and the steady (ERS-2 – POSEIDON) series. Similar results have been found by Queffeulou (2000).

6 SEA STATE BIAS LONG TERM MONITORING

Figure 9 shows the sea state bias (SSB) coefficient A obtained with the BM1 model (SSB = A x SWH). No SSB change versus time can be deduced from figure 9, which is an expected result because of the stability of the SWH with time.

7 ALTIMETER SEA SURFACE HEIGHT LONG TERM MONITORING

7.1 USING OPR DATA ONLY

OPR data have been upgraded using USO drift measurements and SPTR jumps range corrections, available at ESA/ESRIN. New SPTR corrections have been made available to the users at the mid of December 2000 for ERS-1 and ERS-2. It has been shown (Martini and Femenias, 2000) that these new corrections, on one hand, significantly reduce the standard deviation of the (ERS-2 – ERS-1) SSH differences during the tandem phase (from 1.4 cm with the old SPTR corrections to 0.8 cm with the new ones), but on the other hand, increase the mean (ERS-2 – ERS-1) SSH difference by about 2.5 cm, leading to a mean (ERS-2 – ERS-1) bias of about 4 cm (instead of about 1.5 cm with the old SPTR corrections). Figure 10 shows the cycle mean (top curve) and standard deviation (bottom curve) of the (ERS-2 altimeter SSH – OSU95 mean SSH) difference as function of the ERS-2 cycle number. Using the older SPTR corrections leaded to observe an increase of the sea surface height for the 25 first ERS-2 cycles. With the new SPTR corrections, the values reported for the first cycles are about 2 cm higher and no drift of the altimeter sea surface height can be evidenced anymore. SSH drops for cycles 50-52 seem to coincide with the start of the new platform piloting, but such drops may not be the consequence of the mispointing of the altimeter alone. If we assume that the 0.2 dB drop in backscatter coefficient from February 10 to March 2 is due to mispointing, then from simulations performed by Soussi and Zanife (1999), a mean corresponding mispointing value of 0.13 degree can be deduced, which leads to a drop in SSH of about 7 to 10 mm for a mean 2 m SWH. This is not enough to explain the 2-3 cm SSH drop observed for cycle 51. As far as the standard deviation of the (ERS-2 altimeter SSH – OSU95 mean SSH) difference is concerned, there is an increase of this parameter versus time. Possible candidates responsible of this increase are the orbit quality which proved many times in the last 20 cycles to be poorer, and also the ionospheric correction quality which also is poorer in high solar activity period (the solar activity maximum occured in 2000).

7.2 AT ERS/TP CROSSOVERS

Direct comparison of sea surface height difference between ERS-1 and ERS-2 along collinear tracks was performed during the tandem phase : the mean of the SSH differences provided a direct estimate of the relative bias between the ERS-1 and ERS-2 missions. The comparison between TP and ERS-1/2 has been performed by computing sea surface height difference at dual TP-ERS-1/2 crossovers, with a maximum crossover time lag of 10 days. Used during the tandem phase, this crossover method confirmed the ERS-1/ERS-2 results obtained along collinear tracks and allowed to separate the part of the relative bias due to ERS-1 from the part due to ERS-2. Figure 11 shows the ERS-1 - TOPEX, the ERS-1 – Poseidon, the ERS-2 - TP, the ERS-2 – Poseidon and the ERS-2 - ERS-1 sea surface height difference series plotted as function of ERS cycle number, for ERS-1 phases C, E, F, G, and ERS-2 phase A. Each dot reports a mean of the SSH difference over an ERS 35-day cycle, excepted for the ERS-1 geodetic phase (phases E-F) where the ERS-1 data have been split into 37-day sub-cycles, and for the transition between phase F and phase G where cycle 10 of phase F and cycle 1 of phase G are not complete (they have about 15 days of data each). For one ERS 35-day cycle, between 4 to 7 TP 10-day cycles can be used to compute the 10-day time lag TP/ERS crossovers.

7.2.1 (ERS-1 - TOPEX) SSH DIFFERENCE

(ERS-1 - TOPEX) SSH difference values are between 0 and 3 cm (between 1 and 4 cm with the older SPTR corrections). These values implicitly contain the existing mean 0.8 cm wet tropospheric correction difference between the ERS and TP radiometers (see section 7). It means that if the mean radiometer difference was corrected, the SSH differences should be between 0.8 and 3.8 cm. As stated in Stum et al. (1998), sea state bias correction difference between TP and ERS may contribute to this significant TOPEX/ERS SSH bias. Because of the scatter of the individual values, no long-term trend of the SSH difference (if any) can be derived from this data series.

7.2.2 (ERS-2 - ERS-1) SSH DIFFERENCE

The (ERS-2 - ERS-1) SSH difference values are between 3,2 and 4,6 cm (between 0,2 and 3 cm with the older SPTR corrections). The variations of the (ERS-2 - ERS-1) SSH difference from one cycle to the other are much reduced with the new SPTR corrections, and confirms results found by Martini and Femenias (2000). The 1,5 cm jump between ERS-2 cycle 6 and ERS-2 cycle 7 however seems to be due to ERS-2, because the (ERS-1 - TOPEX) SSH difference remain steady, whereas the (ERS-2 - TP) SSH difference is very similar to the (ERS-2 - ERS-1) SSH difference. Deduced from this (ERS-2 – ERS-1) SSH difference series, the relative bias in SSH between the two ERS missions is now about 3,8 cm.

7.2.3 (ERS-2 - TOPEX) SSH DIFFERENCE

The (ERS-2 - TOPEX) SSH difference values are between 3 and 6,2 cm (between 2 and 5 cm with the older SPTR corrections). The (ERS-2 – TOPEX) SSH differences corresponding to the two last cycles before the switch off of the the Side-A altimeter (cycles 38 and 39) are probably 1 cm too low due to the degradation of the TP SSH accuracy. The (ERS-2 – TOPEX) SSH differences with the Side-B altimeter seem to be homogeneous with those from the beginning of the ERS-2 mission. The (ERS-2 – TOPEX) and (ERS-2 – Poseidon) SSH differences corresponding to ERS-2 cycles 50 to 52 are the lowest of the series (probably 1 to 2 cm too low) : this result is consistent with the (ERS-2 SSH – OSU95 mean SSH) series shown in figure 10, and confirms that something affected the quality of OPR data during these cycles. As explained in section 6.2.1, mispointing alone cannot explain the 2 cm ERS-2 SSH drop for cycle 50-52.

8 RADIOMETER WET TROPOSPHERIC CORRECTION MONITORING

8.1 COMPARISON WITH THE ECMWF MODEL WET TROPOSPHERIC CORRECTION

Figure 12 shows the mean and standard deviation of the (ECMWF model – ERS-2 radiometer) wet tropospheric correction difference. The values for the ERS-1 radiometer during the tandem phase are also shown. From December 1st 1997, (mid of cycle 27), the wet tropospheric correction derived from the ECMWF model has been improved in Meteo-France, leading to much better agreement now with the radiometers on board TP and ERS. No radiometer drift can be deduced from the wet tropospheric correction difference series : the long term variations of the difference are due to the variations of the model wet tropospheric correction quality. The standard deviation of the difference is lower and lower from the beginning of the ERS-2 mission and seems to be an indicator of the continuous improvement of the model quality.

8.2 AT ERS/TP CROSSOVERS

Comparison between the TOPEX microwave radiometer (TMR), the ERS-1 microwave radiometer (ATSR/M) and the ERS-2 microwave radiometer (MWR) has been carried out following the method detailed in Stum (1998). It consists in comparing the measurements of the three satellites at TP/ERS crossover points with less than 1-hour time lag. Estimates of the differences are made over time periods of 12 TP cycles, to get homogenous and repeatable sampling of the atmosphere. The mean value of the (TMR – ERS) wet tropospheric correction difference at these crossovers is computed. To study the drift over time of this mean value, it is first necessary to intercalibrate ERS-1 and ERS-2 radiometers at the mm level. Using data from the tandem phase shows that the mean ERS-2 path delay is about 1 mm higher than the mean ERS-1 path delay, with variations from 0.04 mm for low path delays (less than 10 cm) to 4 mm for high path delays (more than 30 cm). In the following, ERS-2 path delays have thus been corrected for this value, to be fully homogeneous with ERS-1 at the mm level.

Figure 13 shows the (TP - ERS) crossover mean wet tropospheric correction difference versus the series of 12 TP cycles time period. The standard TMR path delay reported on the TP GDR is used. The abscissa of each reported value is referred to the middle of the 12-cycle period (e.g. for the 12-cycle period 2 to 13, the abscissa is 7). The beginning of this time period corresponds to cycle 6 of ERS-1 phase C, and the end, to ERS-2 cycle 56. Note also that ERS-1 phase D data have been included here (3-day cycles between January and March 95).

Two different regimes seem to occur : a regular drift from the beginning up to TP cycles 150-160, at a rate about -1 or -1.5 mm/year, followed by a jump to a plateau (the last 10 points). The drift over time of the TMR 18 GHz channel (Ruf, 2000, Keihm et al., 2000) explains the (TMR – ERS) relative drift observed up to TP cycles 150-160. Figure 14 shows the plot over time of the difference in TMR path delay between the ouput of the standard GDR 3-frequency (18/21/37 GHz) algorithm and the output of a two-frequency (21/37 GHz) algorithm. This algorithm has been designed by Obligis et al. (1999) and provides a good estimate of the path delay using two channels only, as is the case for the ERS-2 radiometer compared to TMR. Each dot depicts the mean over one TOPEX cycle of this difference. Superimposed are a cubic polynomial regression fit (bold line) over the whole time period, and two linear regression fits, one with data before december 1996 (cycle 158) and one with data after december 1996. Although the drift is lower after this date, there is no evidence that this drift is zero from this date, as may be concluded from the results by Keihm et al. (2000). Therefore, from the drift values reported on figure 14, the following TMR path delay correction formulas have been applied as function of TP cycle number :

$$\text{TMR corrected for cycle } i = \text{TMR GDR for cycle } i + (i-1) * \frac{0.115}{36} \quad \text{for } 1 \le i \le 160$$

$$\text{TMR corrected for cycle } i = \text{TMR GDR for cycle } i + 159 * \frac{0.115}{36} + (i-160) * \frac{0.0486}{36} \quad \text{for } i > 160$$

where TMR path delays are positive and given in cm.

The (corrected TMR – ERS) wet tropospheric correction difference series is shown in figure 15. There is an increase of the difference after TP cycle 157. In figure 16 have been reported the (TMR 21 GHz – ERS 23.8 GHz) brightness temperature difference series. If the TMR 21 GHz brightness temperature is assumed steady with time (this seems to be the case from the results by Keihm et al. (2000)), we may conclude from figure 16 that there is about a 0.5 K to 1K decrease of the ERS-2 23.8 GHz brightness temperature between cycle 157 and cycle 295. Figure 17 shows the mean ERS-2 23.8 GHz brightness temperature versus the ERS-2 cycle number. Although the series is dominated by the annual cycle, when looking at the data after ERS-2 cycle 12 (during which the 23.8 GHz channel experienced a large gain fall), and keeping in mind that a strong El Nino episode occurred during one year around cycle 30 (thus leading to enhanced values of the 23.8 GHz TBs), the 0.5 K to 1K decrease of the 23.8 GHz TB deduced from figure 16 seems to be observed on figure 17.

9 CONCLUSIONS

The variation with time of the OPR Altimeter data quality has been examined using statistical analysis performed on the following OPR parameters :

- the significant wave height
- the backscatter coefficient
- the sea state bias
- the altimeter sea surface height
- the radiometer wet tropospheric correction

Looking at these parameters, and/or at their differences with those of the TP mission, leads to the main following results :

- There is no evidence of significative wave height degradation or trend over time
- The ERS-2 backscatter coefficient experienced a series of (small) jumps at the beginning of year 2000, part of which are due to the platform attitude control degradation. It never recovered its previous level and is now about 0.1 dB lower.
- The noise level of the sea surface height statistics series remains too high to make evidence of a drift (if any) of sea surface height over time, despite the improvement of the SPTR corrections. The mean sea surface height difference between the ERS-1 and ERS-2 missions is now about 3.8 cm.
- The ERS-2 radiometer wet tropospheric correction (and 23.8 GHz brightness temperature) are suspected to be respectively about 5 mm lower (and 0.5 K to 1 K lower) now compared to the beginning of the mission.

Year 2001 will be the year of ENVISAT launch. It is obvious that the present work needs to be continued and consolidated with the next OPR cycles. Informations on the platform attitude control, improvements of the SPTR corrections, assessment of the IF filter shape evolution, monitoring of the radiometer are some of the important issues to be adressed for a suitable intercalibation of the ERS and ENVISAT missions.

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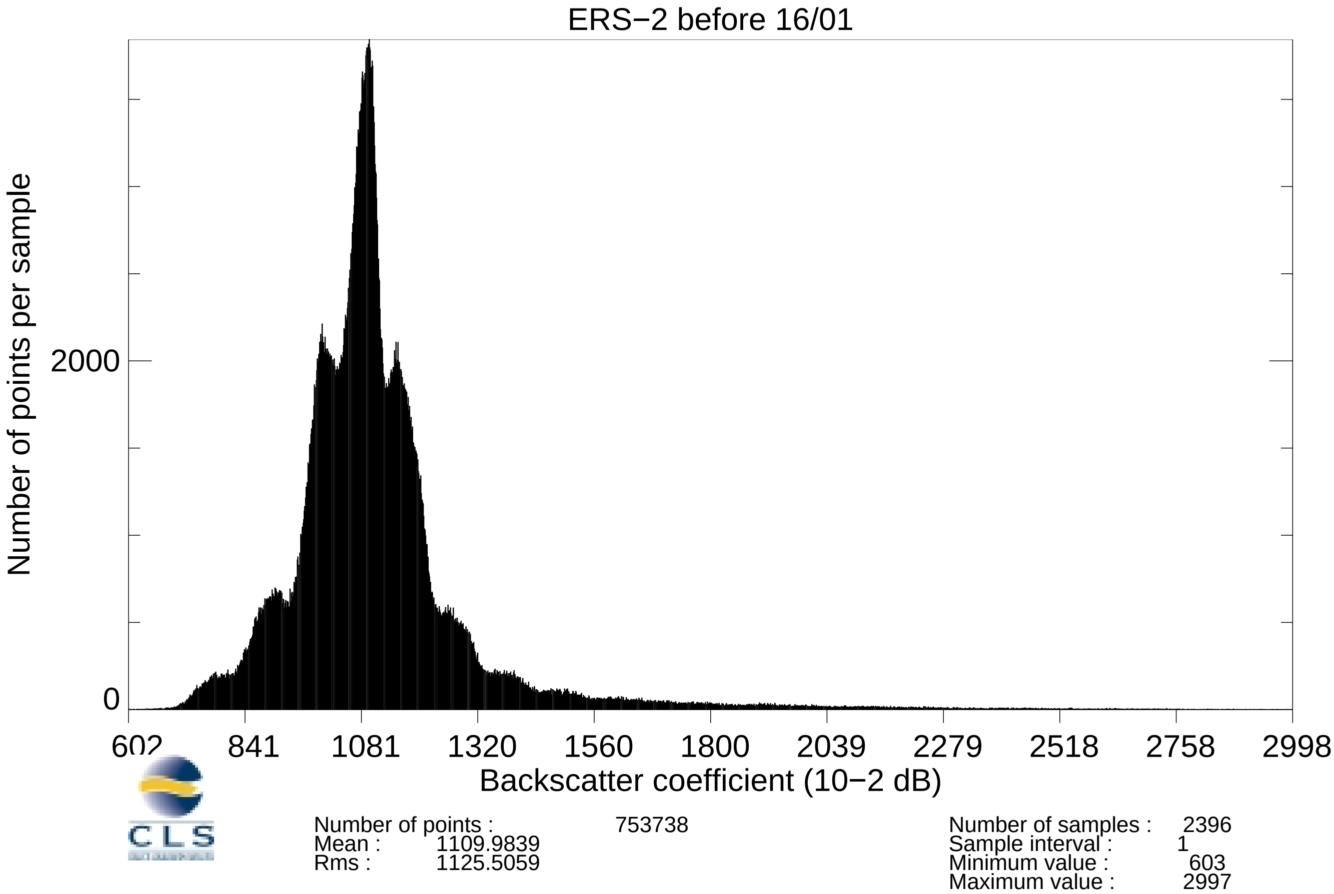


Figure 1 - Histogram of the ERS-2 OPR backscatter coefficient before January 16, 2000

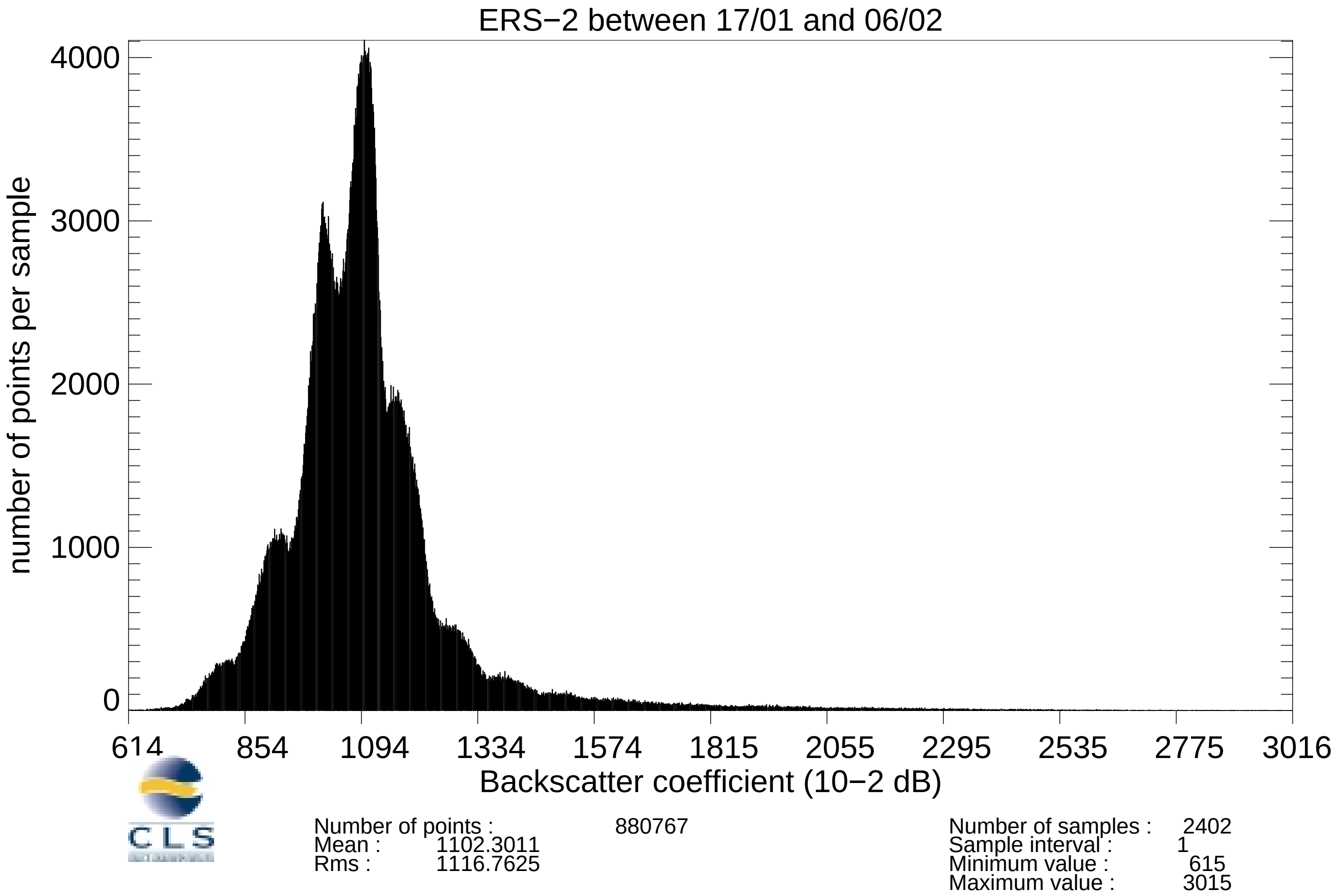


Figure 2 - Same as figure 1 excepted between January 17 and February 6, 2000

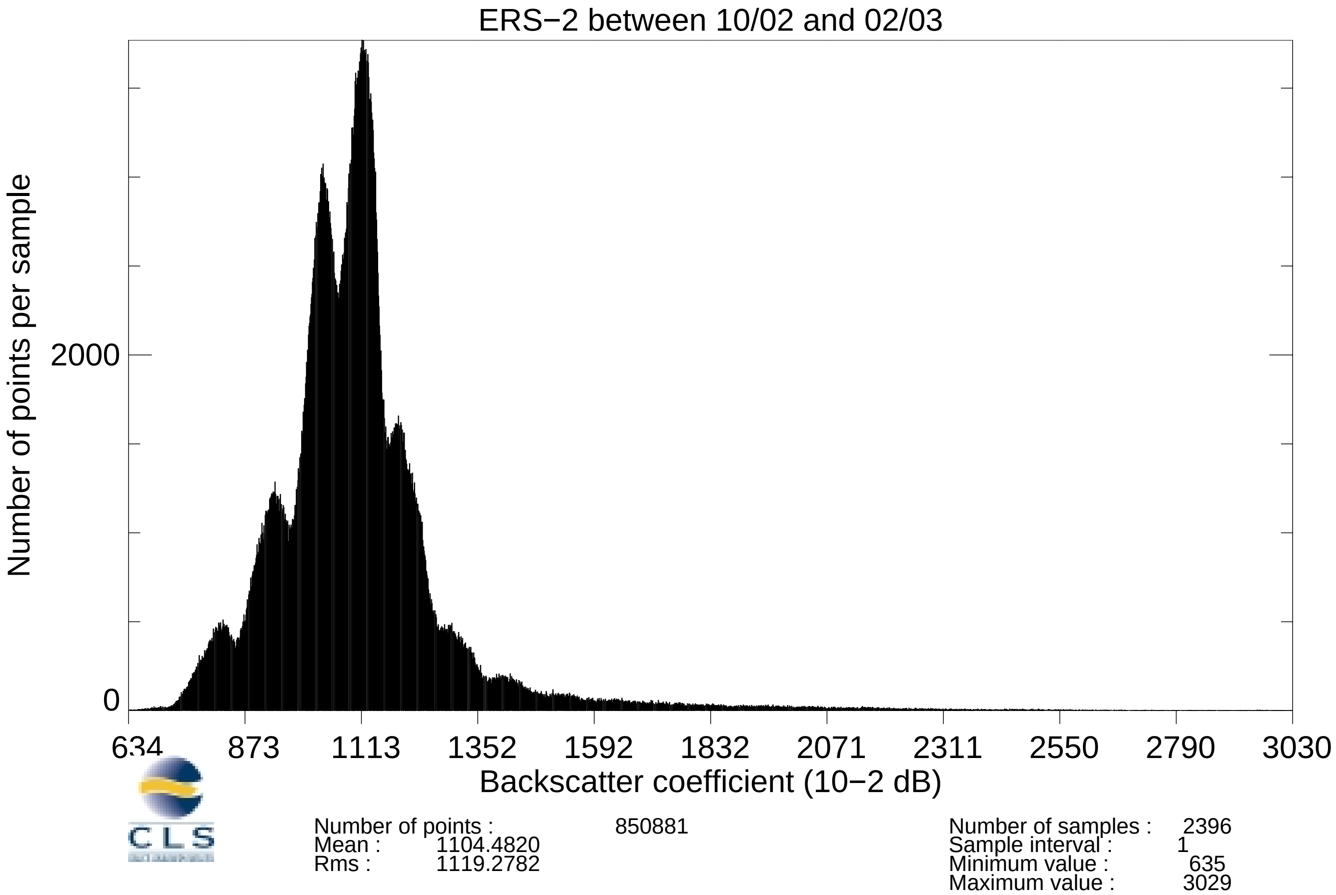


Figure 3 - Same as figure 1 excepted between February 10 and March 2, 2000

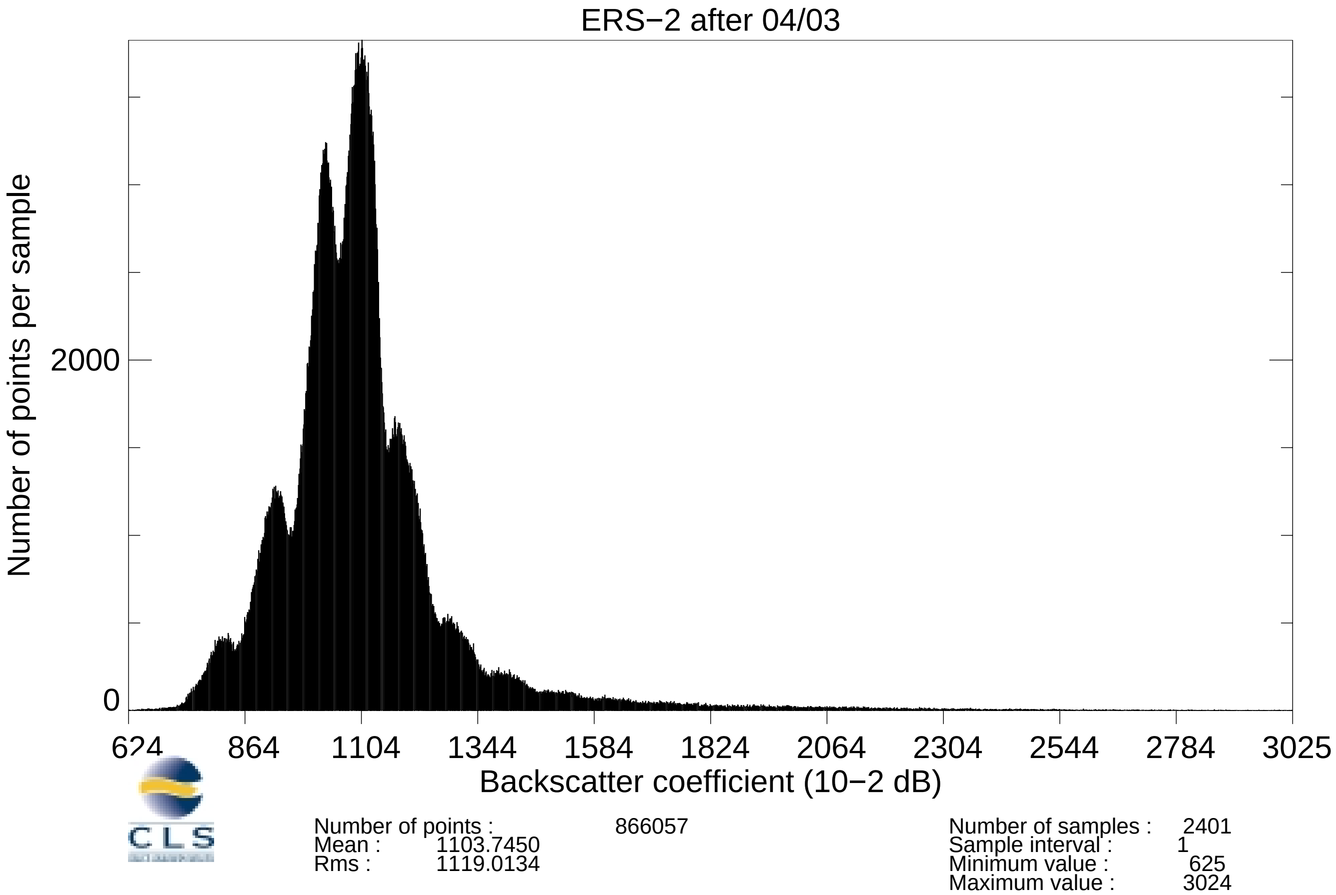
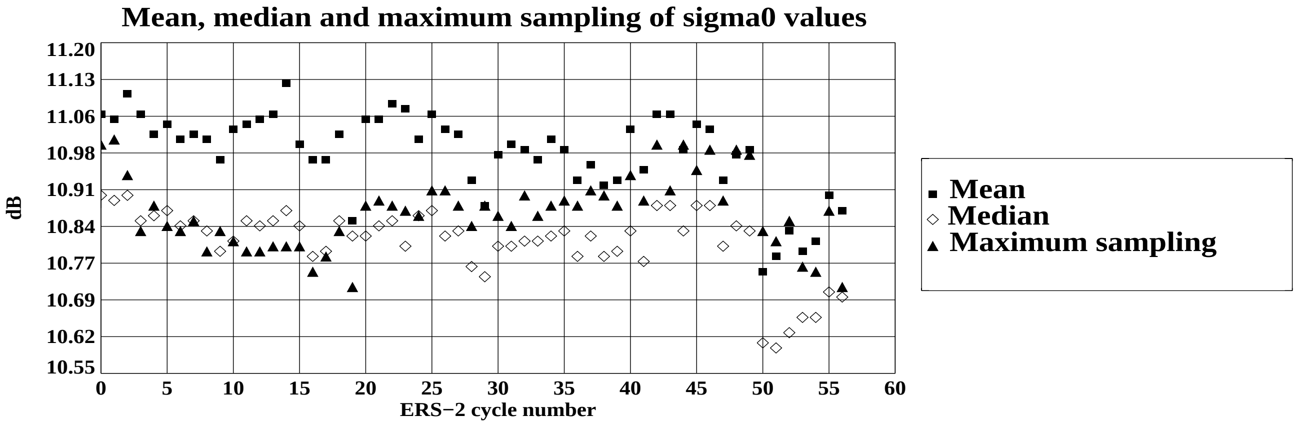
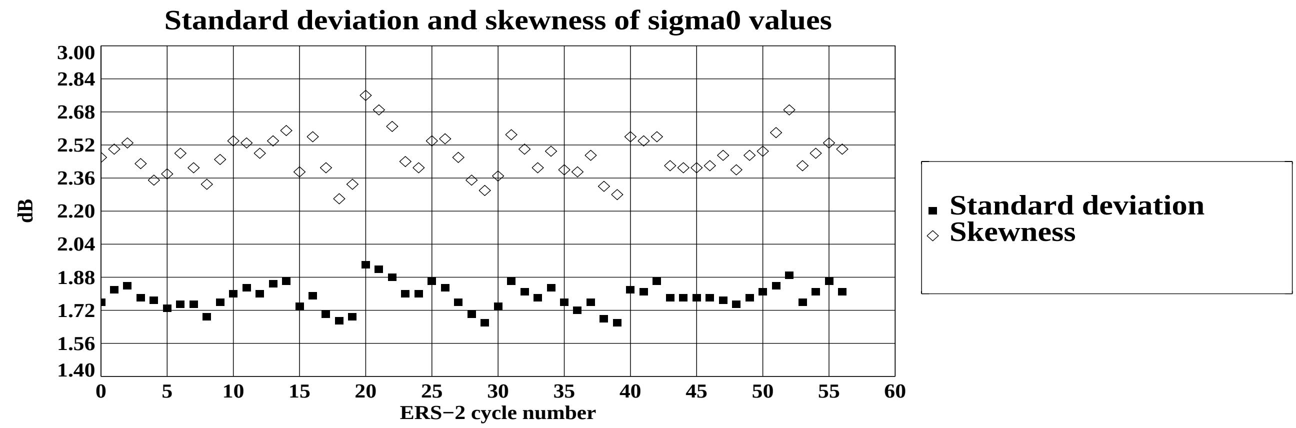


Figure 4 - Same as figure 1 excepted after March 4, 2000





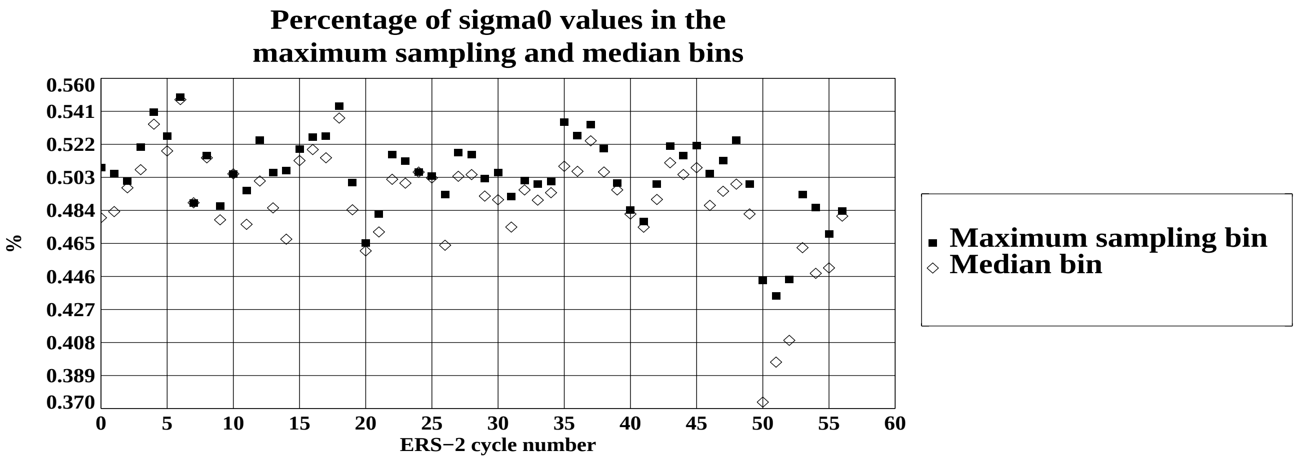


Figure 5 - Statistical results on the ERS-2 OPR backscatter coefficient, as function of ERS-2 cycle number

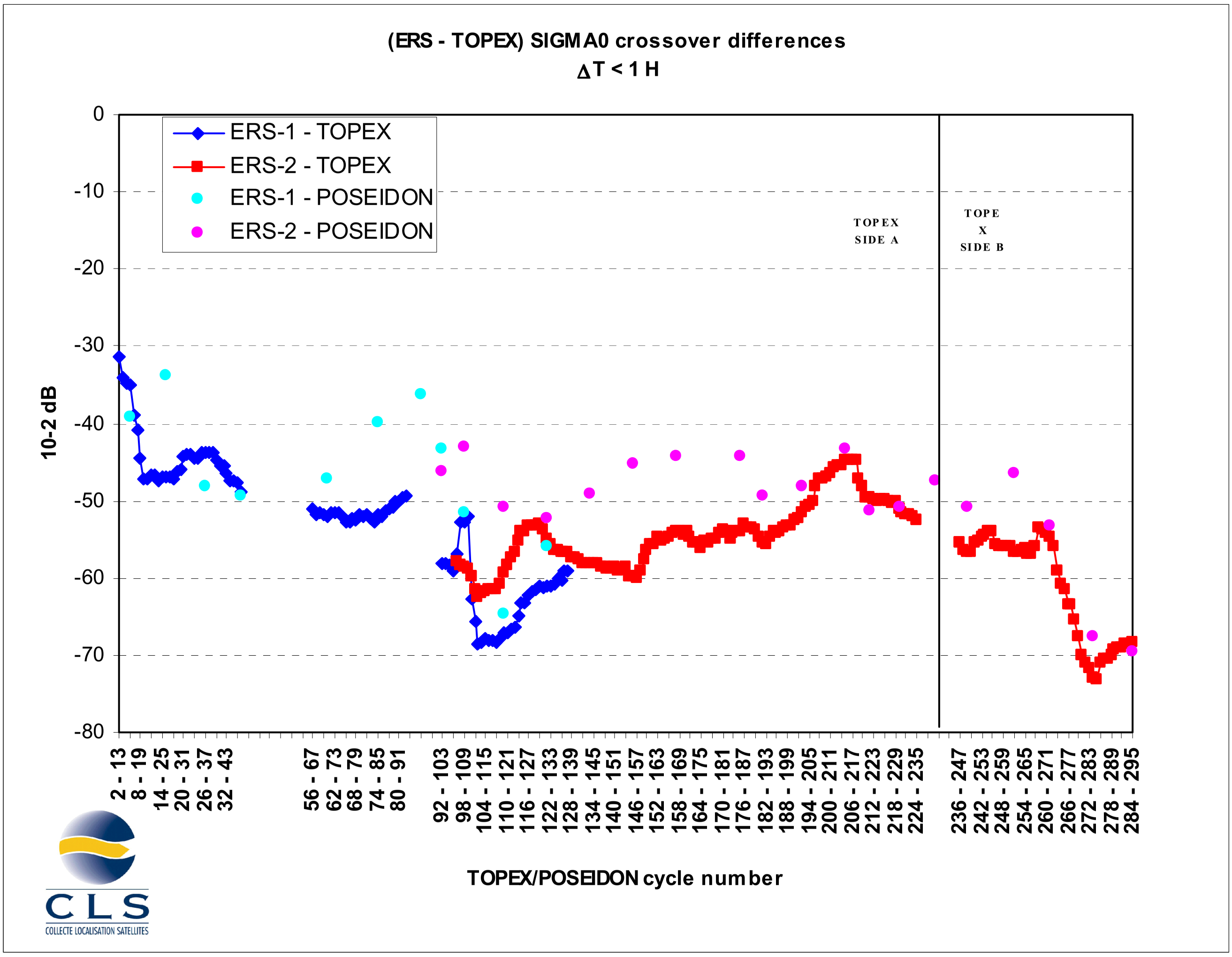
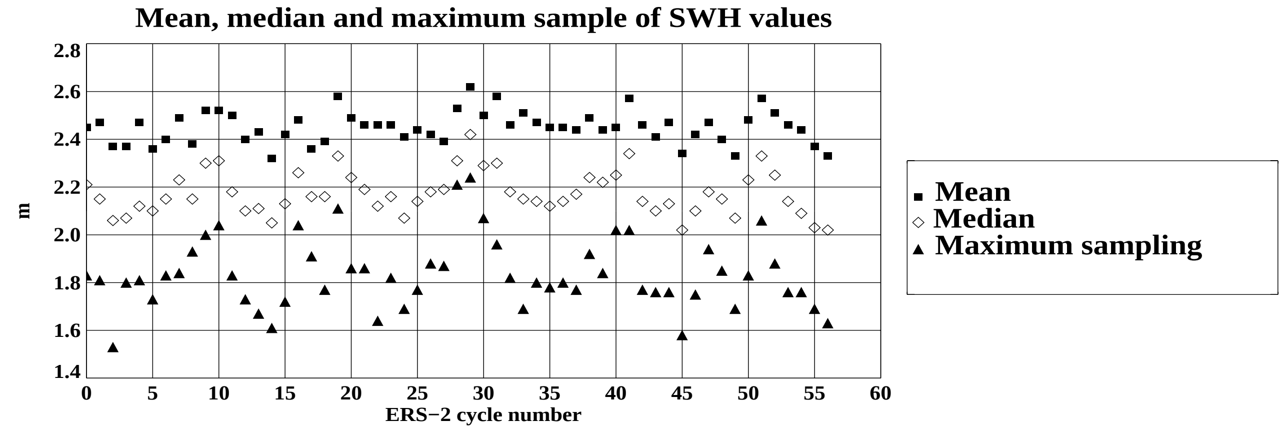
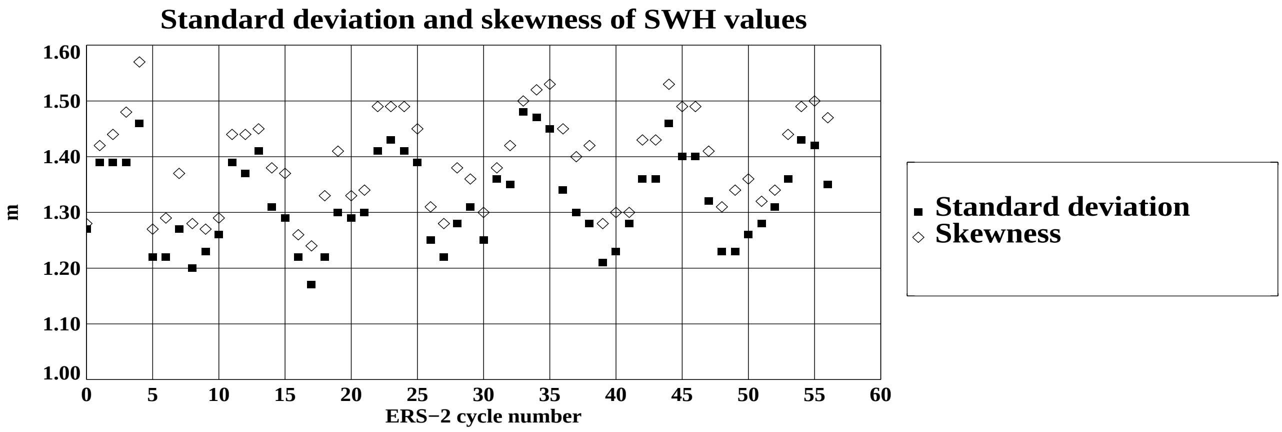


Figure 6 - (ERS-1/2 – TP) Ku-band backscatter coefficient crossover differences, versus TP cycle number





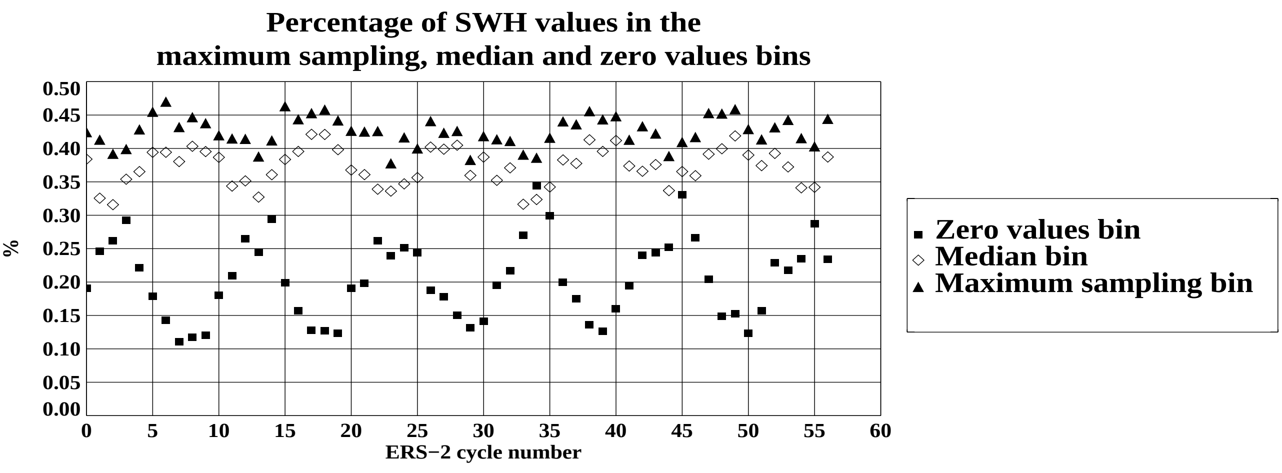


Figure 7 - Same as figure 5 excepted for significant wave height

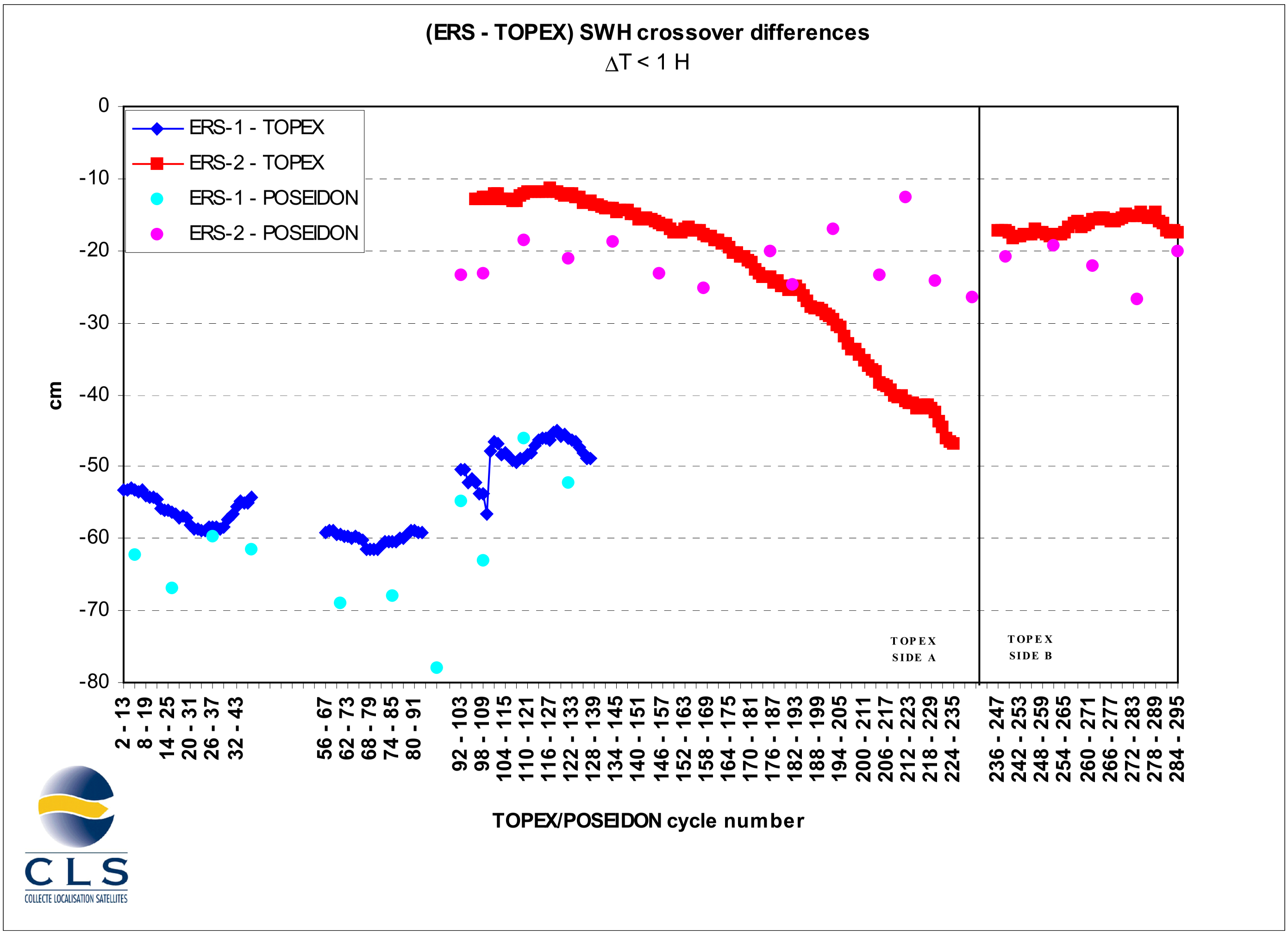


Figure 8 - Same as figure 6 excepted for significant wave height

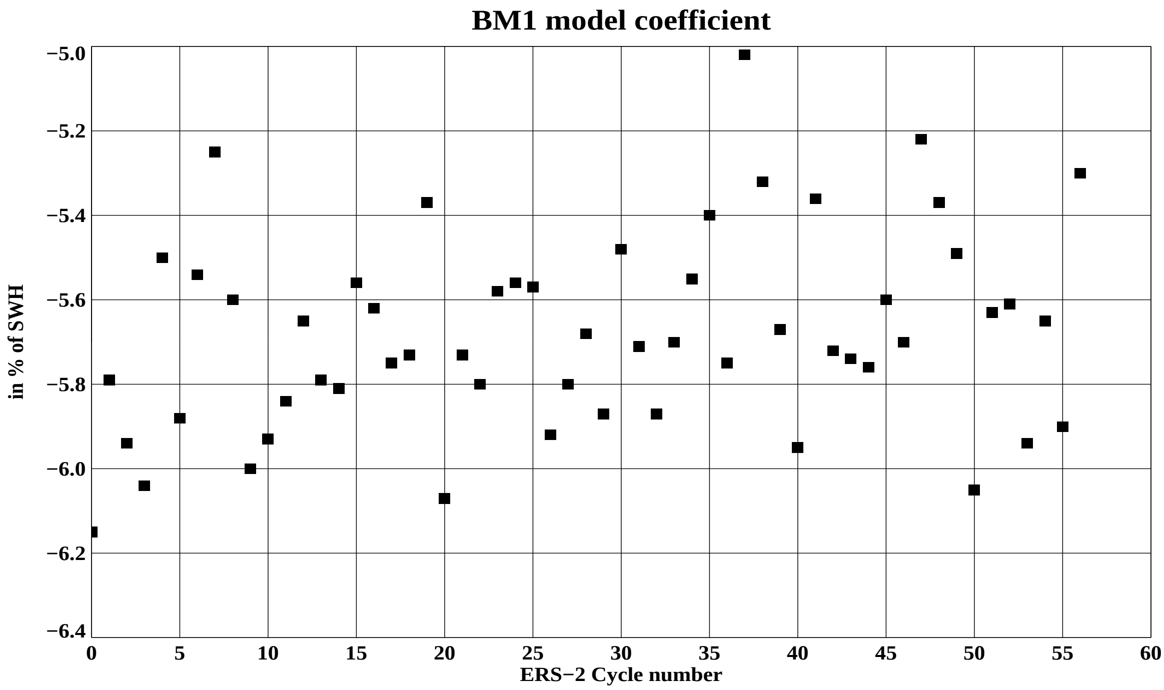
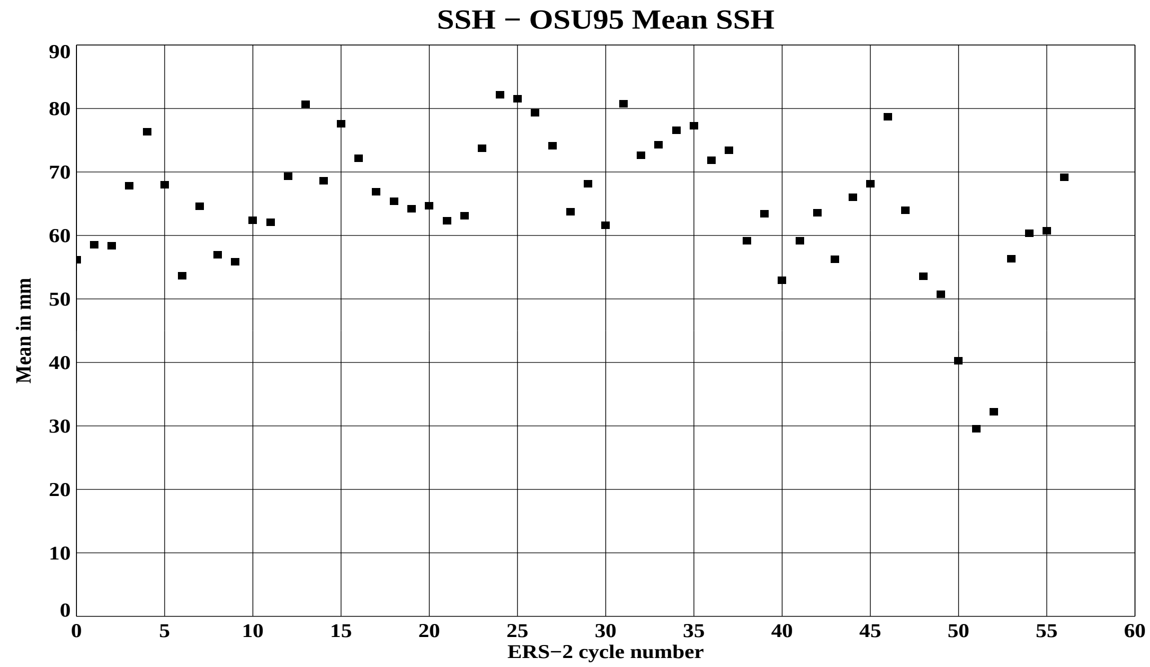


Figure 9 - BM1 sea state bias model coefficient, as function of ERS-2 cycle number



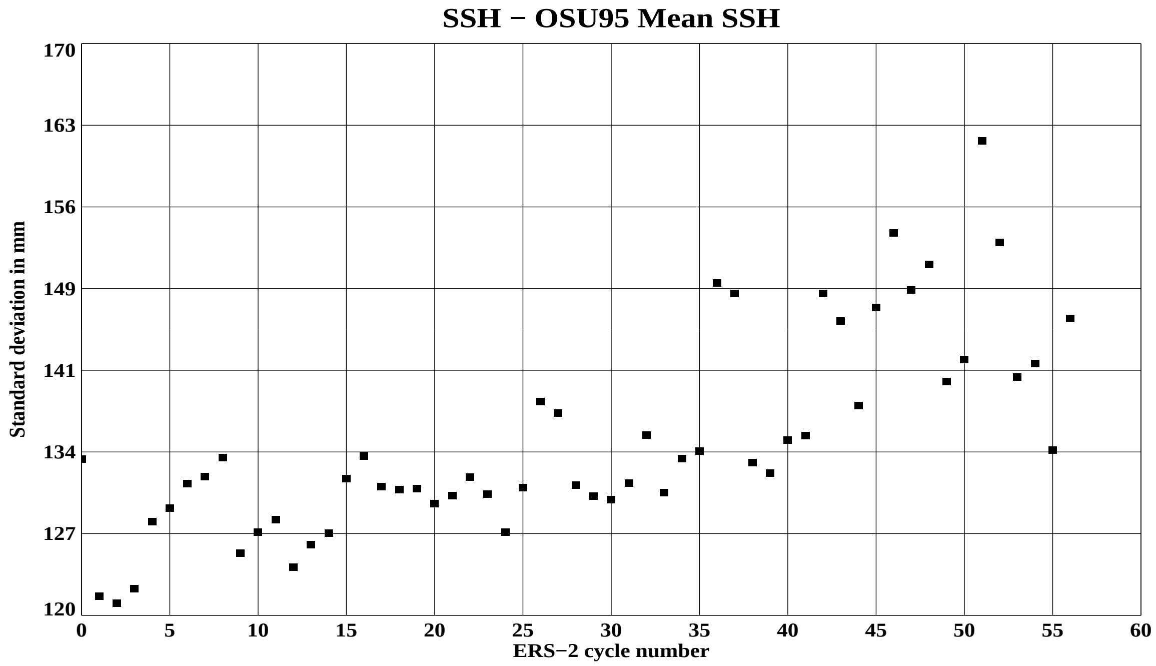


Figure 10 - Mean (on top) and standard deviation (on bottom) of the difference (Altimeter sea surface height – OSU95 mean sea surface height), as function of ERS-2 cycle number

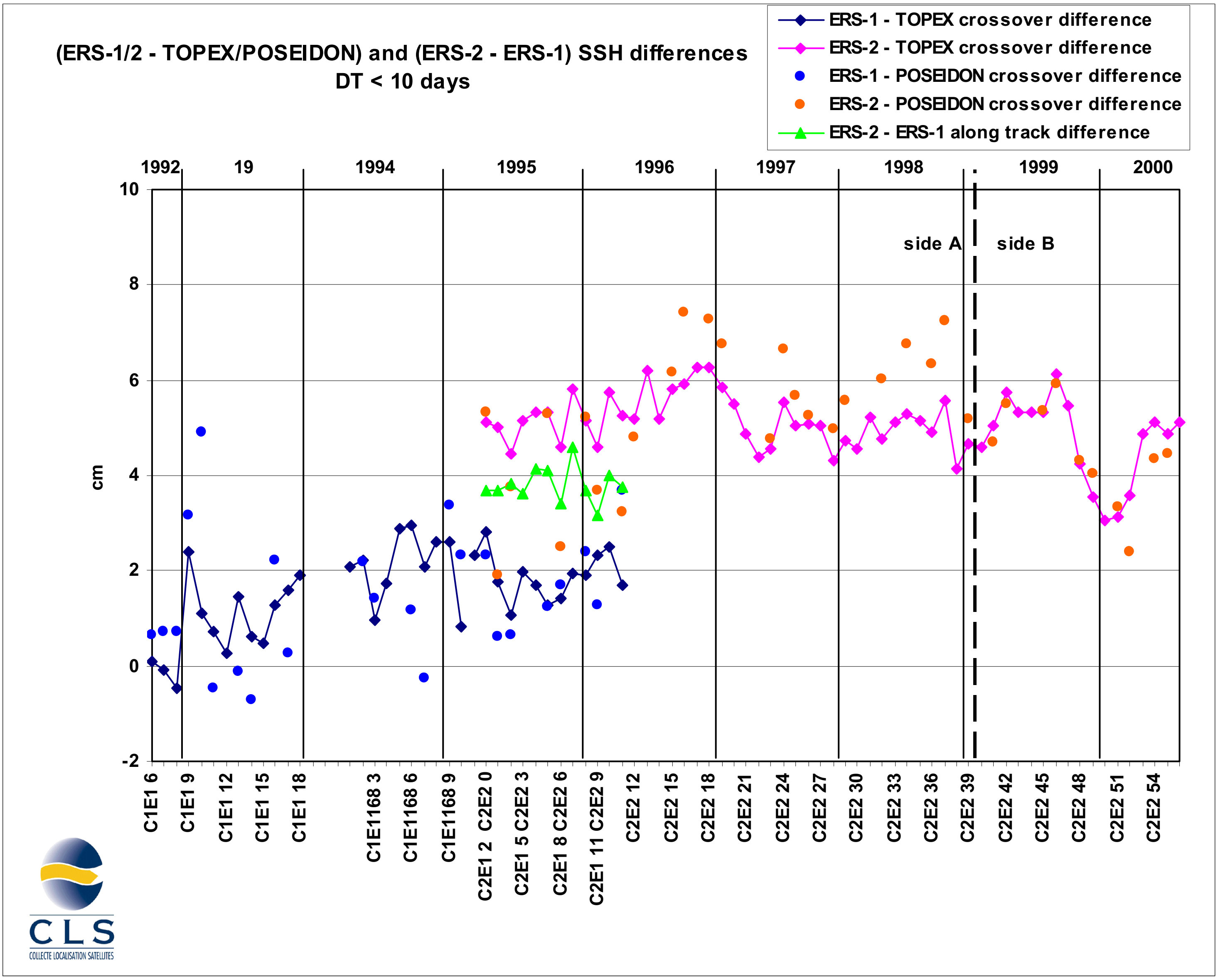


Figure 11 - Mean sea surface height difference (SSH) in cm versus ERS-1 (C1E1 or C2E1) and ERS-2 (C2E2) cycles numbers. The mean SSH difference is computed over one ERS 35-day cycle with SPTR corrections applied, for ERS-1 phases C, E, F and G, and for ERS-2 phase A. The blue series are for ERS-1 – TP crossovers, the pink series are for ERS-2 – TP crossovers (the circles are for ERS-1-Poseidon series), and the green series is for the (ERS-2 - ERS-1) mean SSH difference deduced from repeat track analysis.

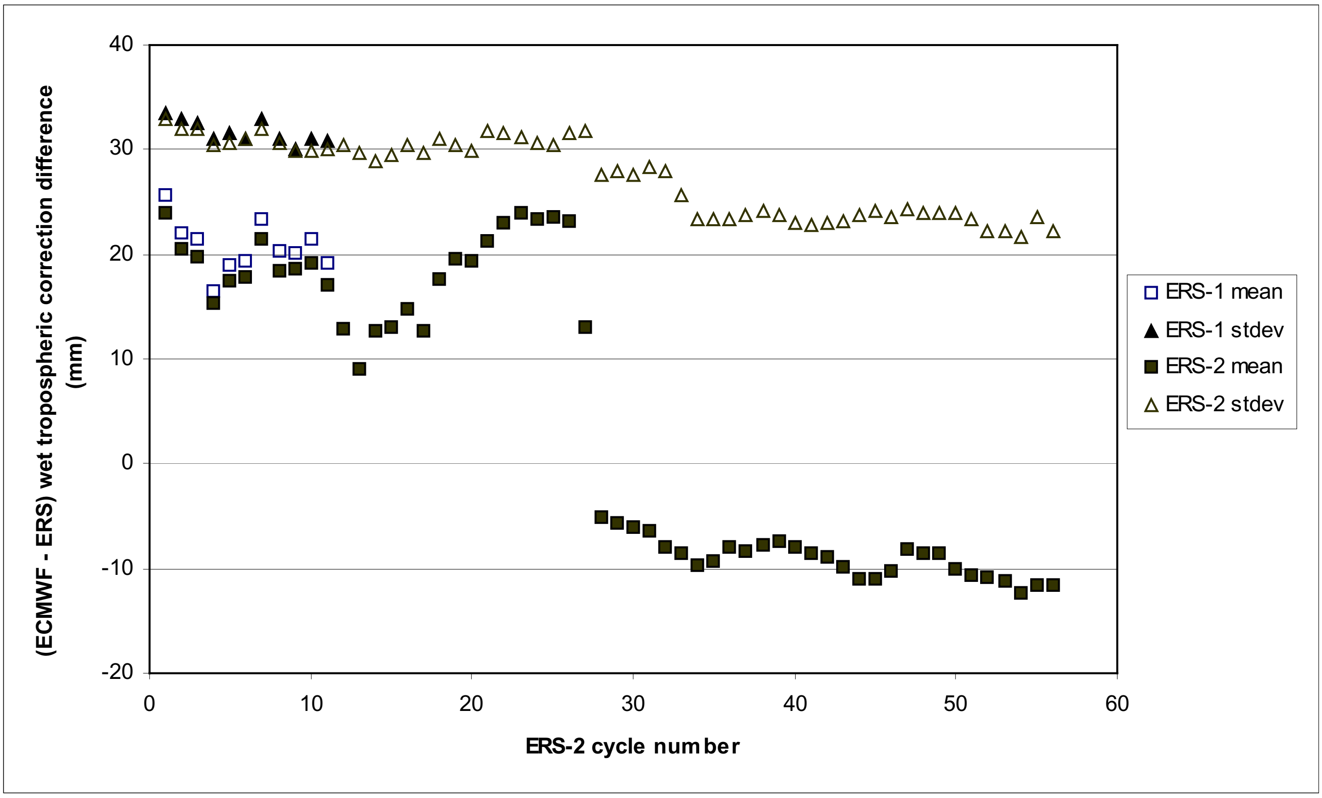


Figure 12 - Mean and standard deviation of the (ECMWF model – ERS radiometer) wet tropospheric correction difference, as function of the ERS-2 cycle number

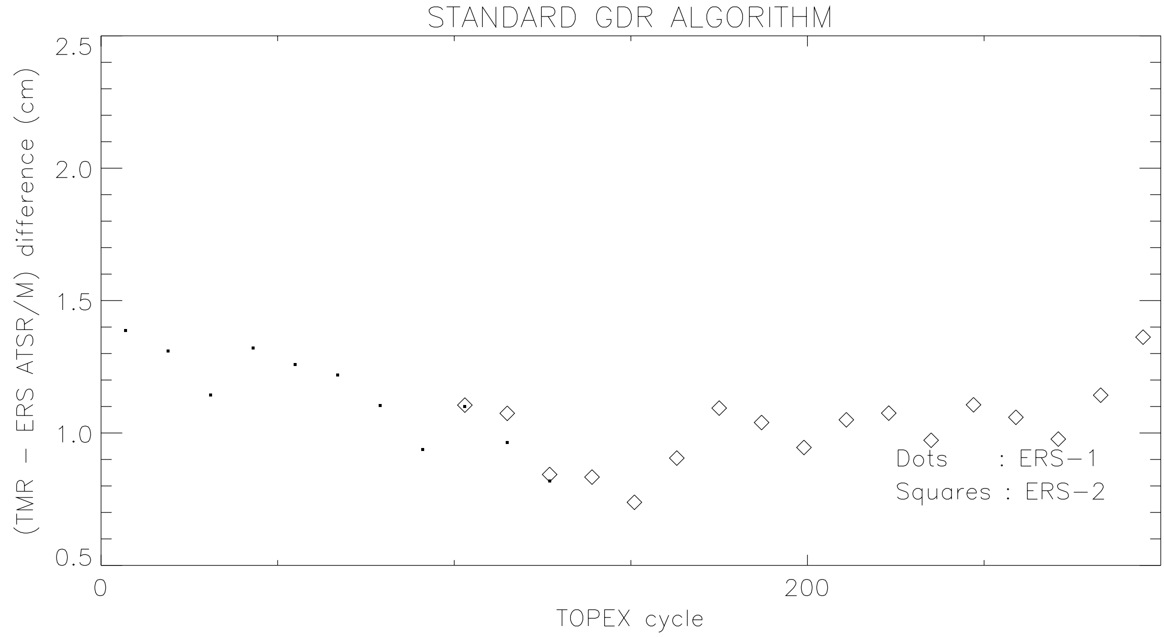


Figure 13 - Mean of the (TOPEX – ERS) radiometer wet tropospheric correction difference, as function of the TOPEX cycle. Each dot is an average over 12 TP cycles.

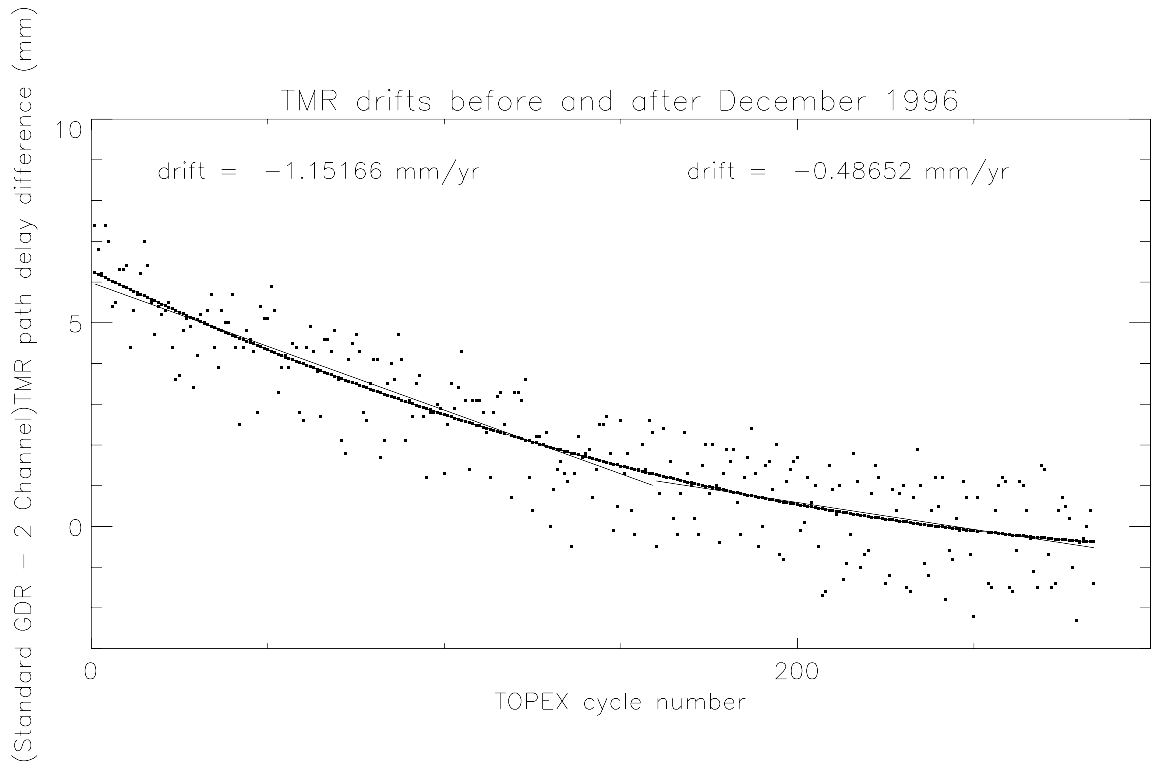


Figure 14 - Mean of the (Standard GDR – two-channel) TMR path delay difference, as function of the TP cycle number. The two channel TMR path delay is computed without the 18 GHz brightness temperature. Each dot is the cycle mean of the difference. Superimposed are a cubic regression fit, and two linear regression lines before and after December 1996. The corresponding drift rates are given on top of the plot.

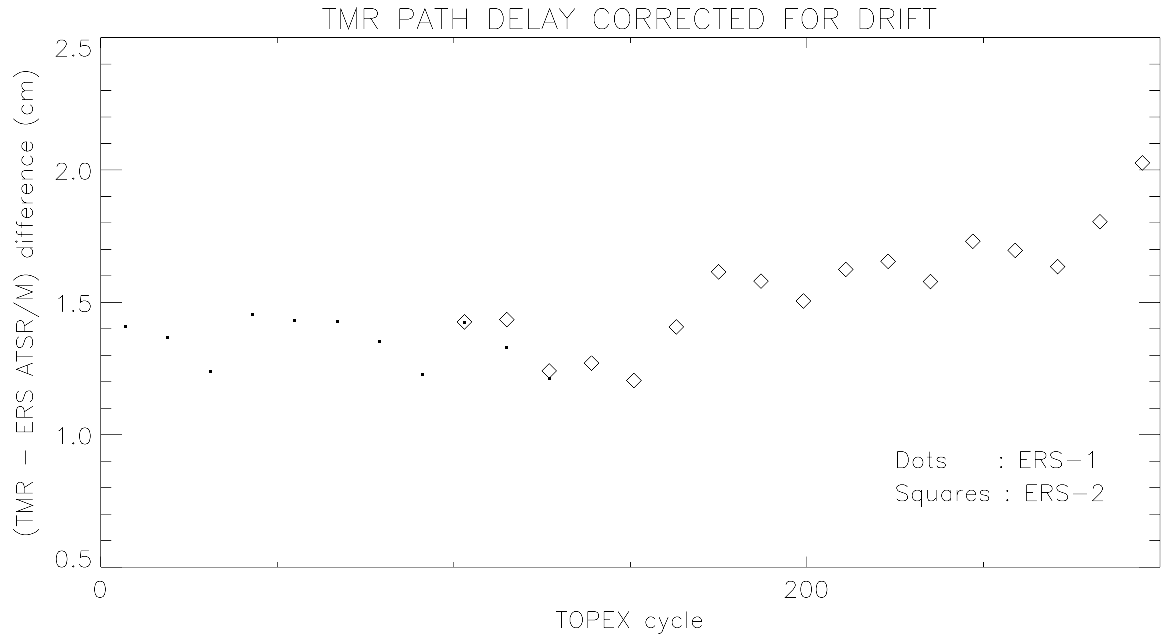


Figure 15 - Same as figure 13 excepted the TMR path delay is corrected for the drift rates given in figure 14.

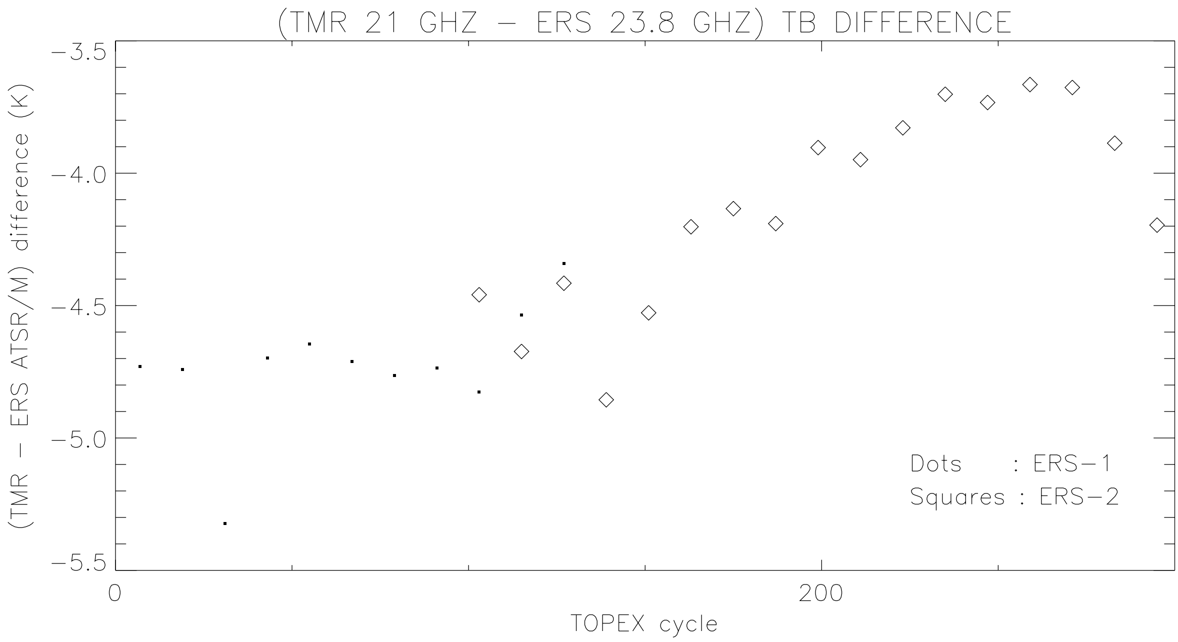


Figure 16 - Mean of the (TMR 21 GHz – ERS 23.8 GHz) brightness temperature difference, as function of the TP cycle. Each dot is a mean over 12 TP cycles.

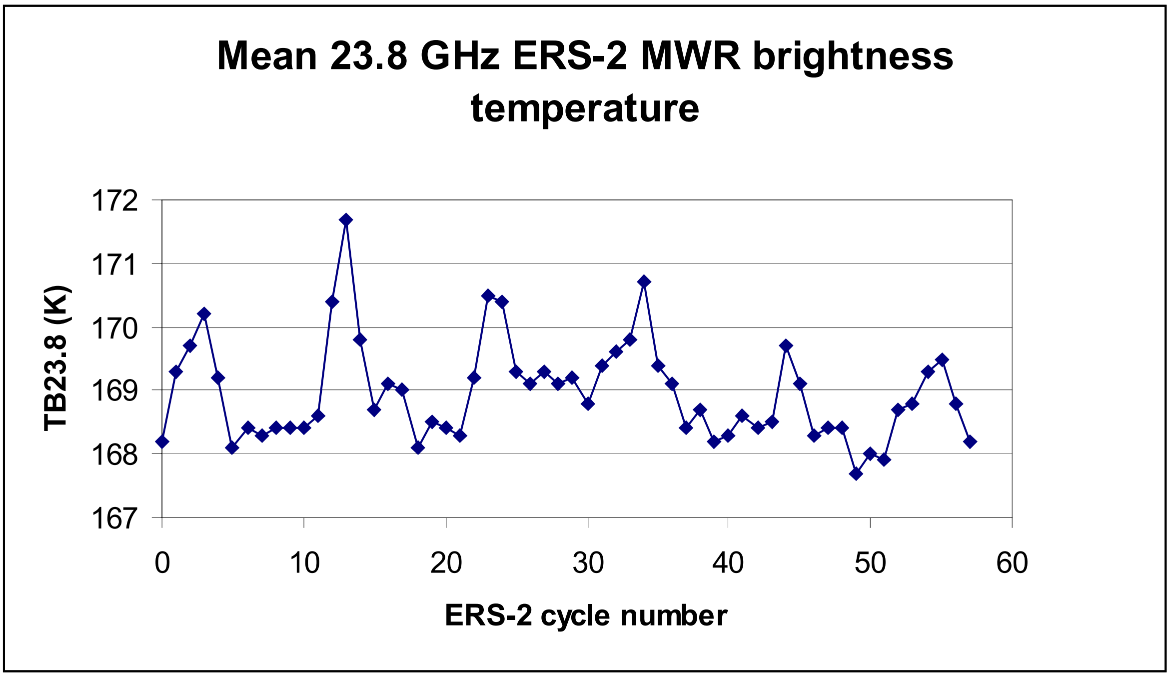


Figure 17 - Cycle mean of the ERS-2 radiometer 23.8 GHz brightness temperature, as function of the ERS-2 cycle number.